Hochstromspeicherring

- M. Droba – Hochstromspeicherring
- P. Nonn – Experimenteller Aufbau
- N. Joshi – Injektiosverfahren
- P. Schneider – Diagnose

O. Meusel (abwesend)

Confinement of non-neutral plasma on magnetic surfaces

Martin Droba

Contens

- Magnetic surface
- Equilibria of Non-neutral plasma (NNP)
- Diocotron instability

Magnetic surface

- Magnetic field lines cover a surface => magnetic surface
- Magnetic coordinates (Ψ,θ,φ)
- Stochastic regions or rational n/m => lost of surfaces

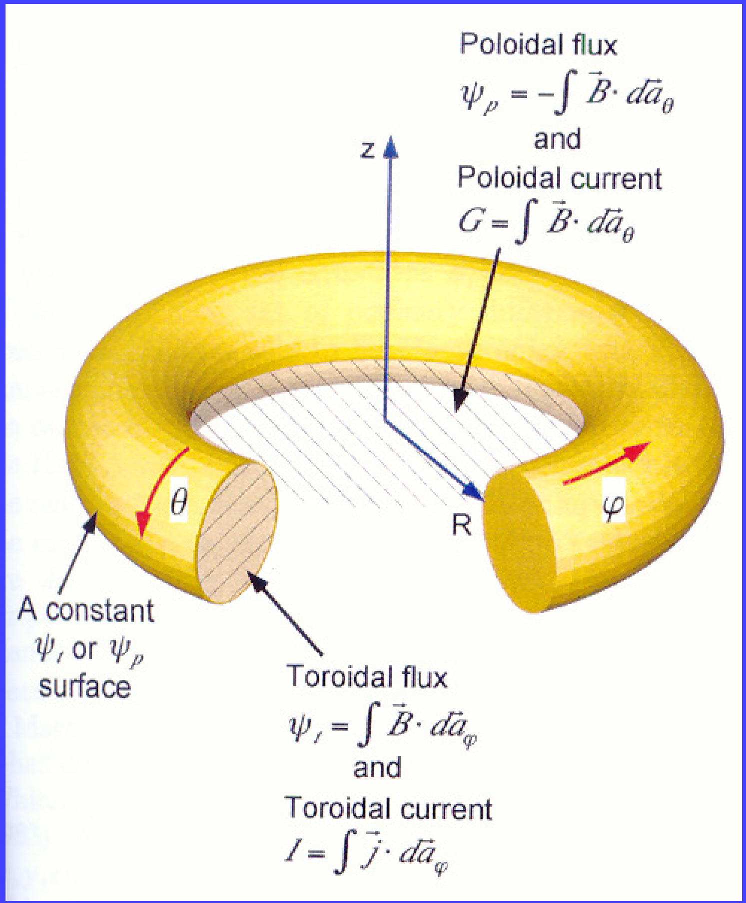
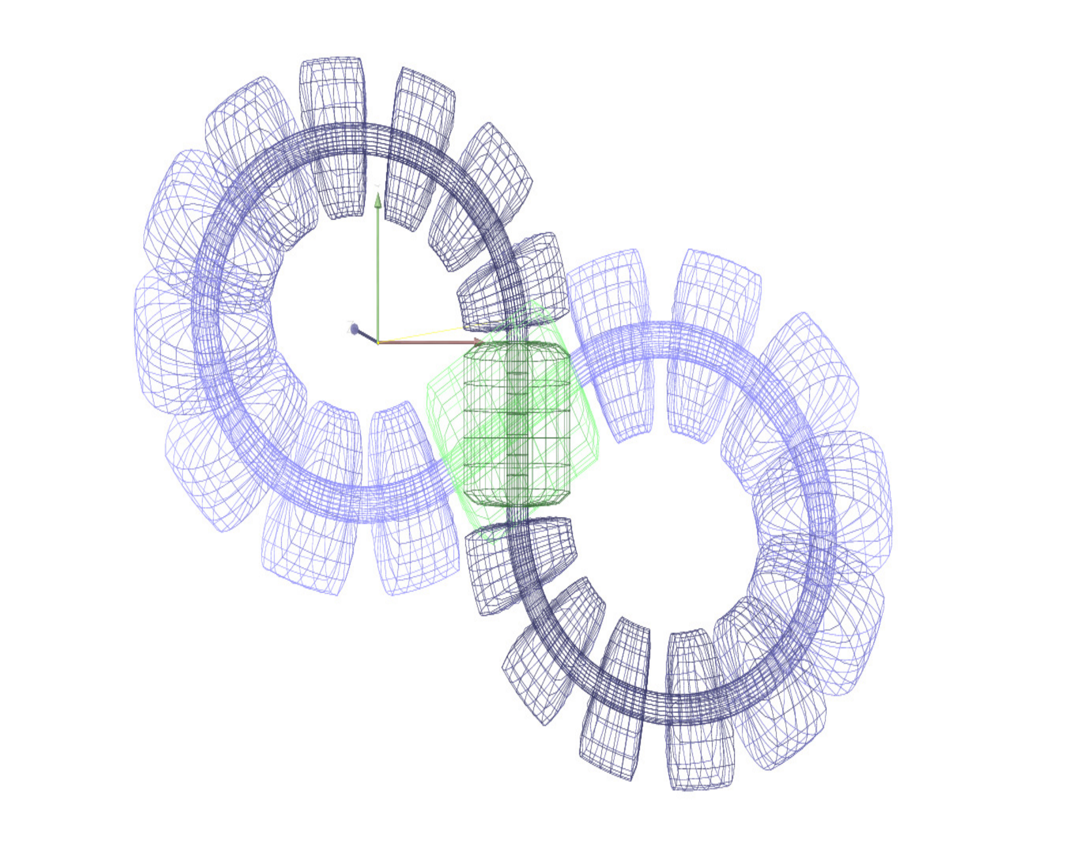
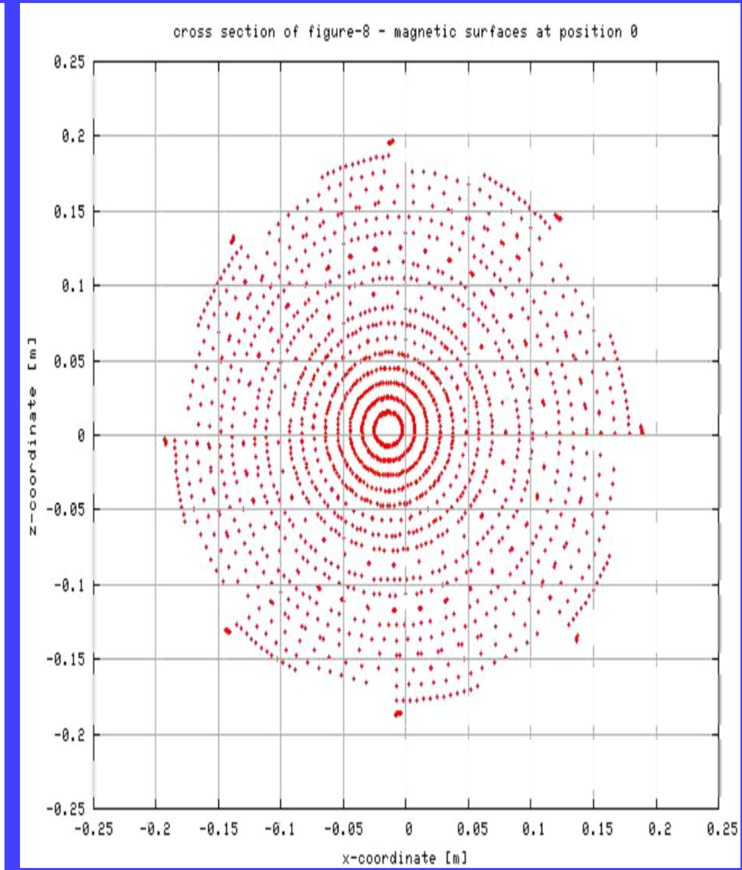


Figure-8 ring with magnetic surface





Fourier transformation and magnetic coordinate system

- Magnetic coordinate system (Ψ,θ,φ)

Periodicity of structure x,y,z ⇔ Ψ,θ,φ

- Field-line integration – (X,Y,Z,B,A...)

$X = \Sigma\, x_{nm} \cdot \exp\{i((n - m\iota)\cdot\chi - (mg+nI)\cdot\theta_0)/(g+\iota I)\} =$

$= \Sigma\, x_{nm} \cdot \exp\{i(n\varphi - m\theta)\}$

$\chi = g(\Psi)\cdot\varphi + I(\Psi)\cdot\theta = \Sigma\, B\cdot dl$

$\theta = \theta_0 + \iota(\Psi)\cdot\varphi$

Other parameters – curvature, B-field, A-potential, torsion

Fourier transformation and magnetic coordinate system

- Magnetic coordinate system (Ψ,θ,φ)

Periodicity of structure x,y,z ⇔ Ψ,θ,φ

- Field-line integration – (X,Y,Z,B,A...) Vacuum configuration I=0

$X = \Sigma\, x_{nm}\cdot\exp\{i((n - m\iota)\cdot\chi - \sout{(mg+nI)\cdot\theta_0})\,/(g+\sout{\iota I})\} =$

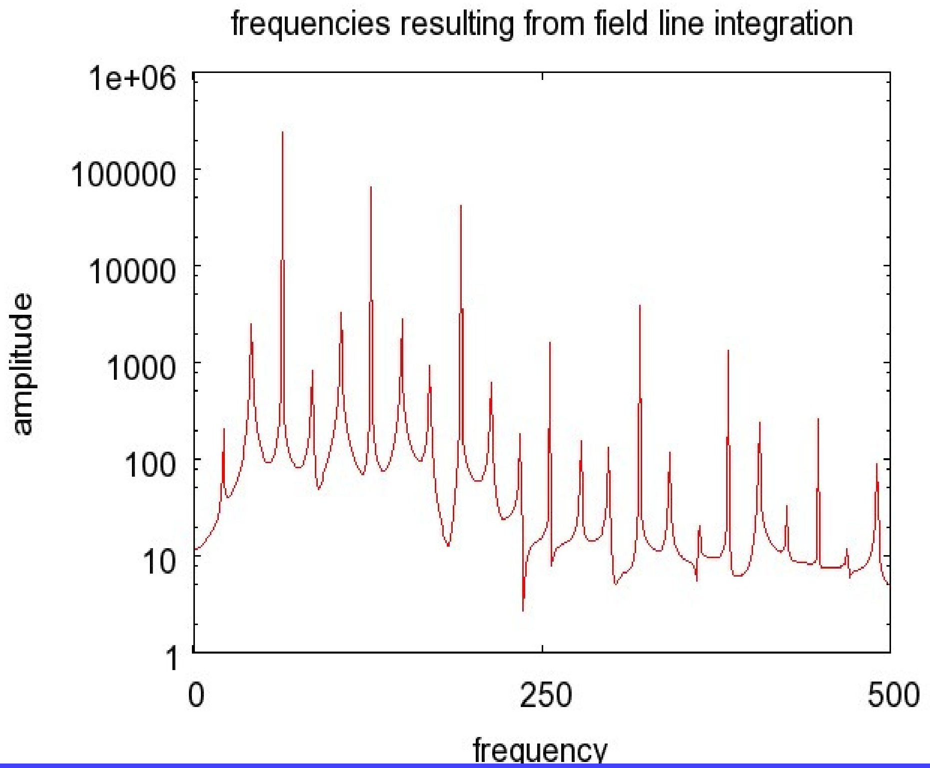
$= \Sigma\, x_{nm}\cdot\exp\{i(n\varphi - m\theta)\}$

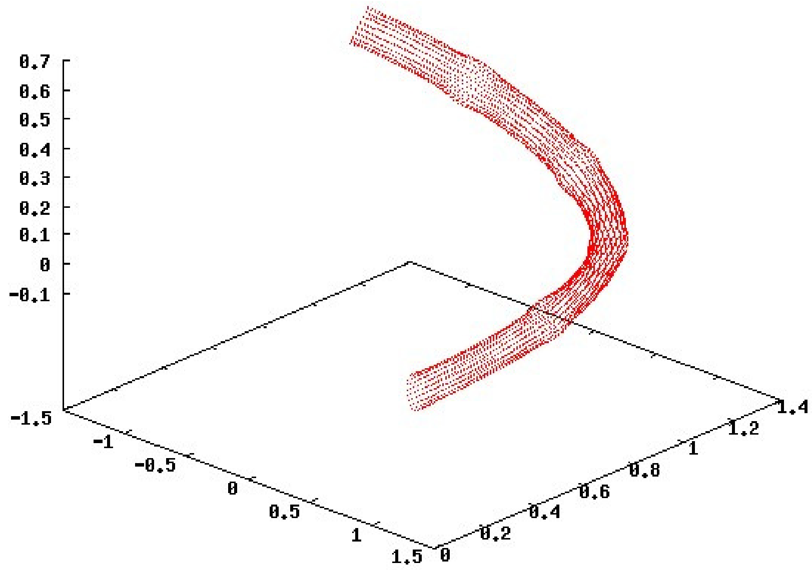
$\chi \;= g(\Psi)\cdot\varphi + I\sout{(\Psi)}\cdot\theta = \Sigma\, B\cdot dl$ → equidistant

$\theta \;= \sout{\theta_0} + \iota(\Psi)\cdot\varphi$ $\quad\theta_0 = 0$ Start condition

Other parameters – curvature, B-field, A-potential, torsion

Example – Figure-8





1D – FFT resulting ω_χ - in 1/N steps

Part of magnetic surface from backward (already 2D) FFT for variables x,y,z

Equilibrium - NNP

Force balance equation - MHD

$m \cdot n \cdot (\partial \mathbf{v}/\partial t + \mathbf{v} \cdot \nabla \mathbf{v}) = q \cdot \nabla \Phi - q \cdot \mathbf{v} \times \mathbf{B} - \nabla p$

Equilibrium $\partial \mathbf{v}/\partial t = 0$, neglecting $\mathbf{v} \cdot \nabla \mathbf{v}$ term, p=nkT and multiplication by **B**

$e \cdot n \cdot \mathbf{B} \cdot \nabla \Phi - e \cdot n \cdot \mathbf{B} \cdot (\mathbf{v} \times \mathbf{B}) - \mathbf{B} \cdot kT \cdot \nabla n - \mathbf{B} \cdot nk \cdot \nabla T = 0$

$\rightarrow e \cdot n \cdot \nabla \Phi = kT \cdot \nabla n \rightarrow$ density $n = n_0(\Psi) \exp\{e \cdot \Phi / k \cdot T(\Psi)\}$

Self consistent potential

$\Delta \Phi = e \cdot n_0(\Psi)/\varepsilon_0 \cdot \exp\{e \cdot \Phi / k \cdot T(\Psi)\}$

Equilibria in 2 limits

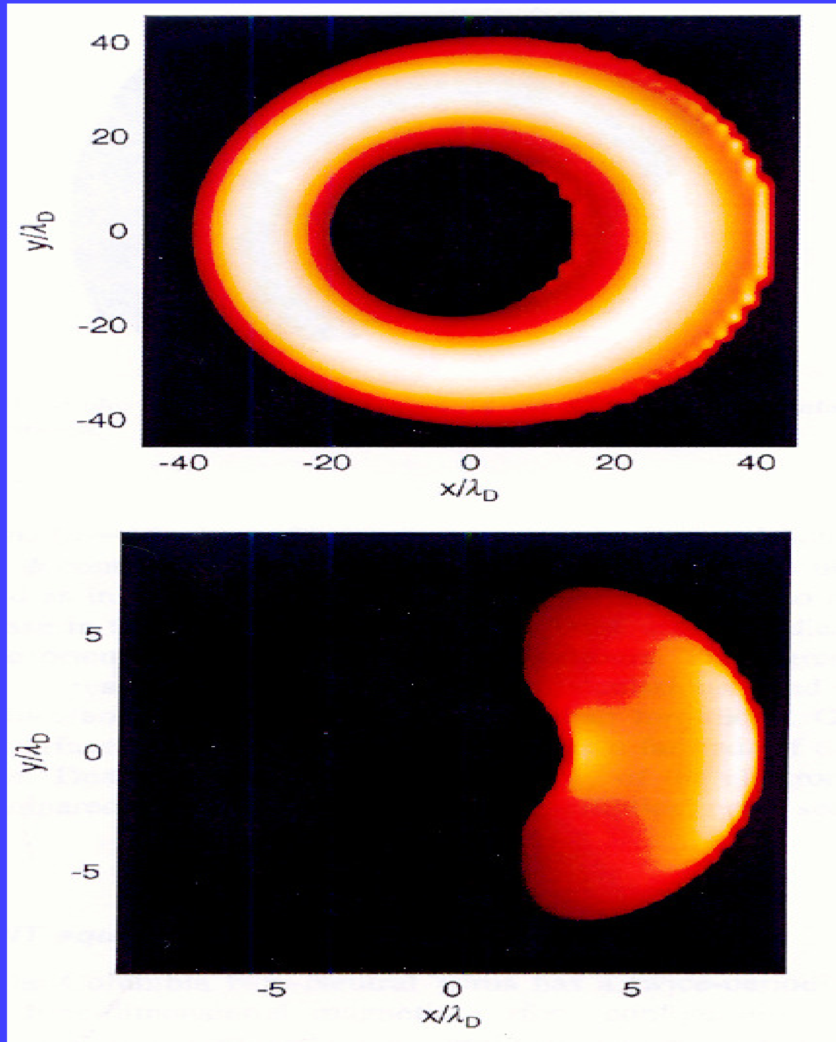
Simulation with biased boundary (cos θ)

- Cold plasma

$a/\lambda_D \sim 10$

- Warm plasma

$a/\lambda_D \sim 1$



Confinement time 1.)

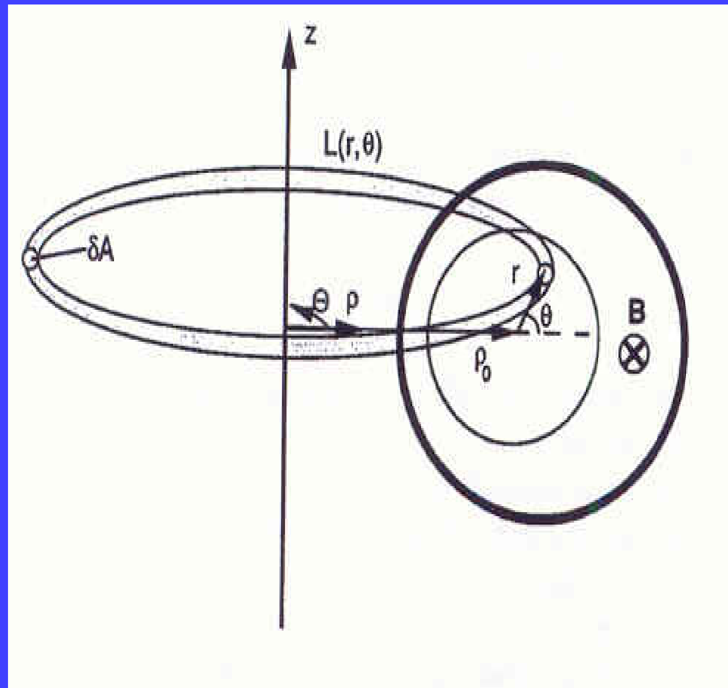
- Without magnetic surfaces – toroidal trap

Variation of magnetic field in tube (similar to magnetic pumping) + momentum conservation =>

$d/dt\ (1/2\langle E_{\parallel,k}\rangle + \langle T_{\perp}\rangle) =$

$= 1/2 \cdot \nu_{\parallel,\perp} \cdot (r / R)^2 \cdot T$ =>

Confinement time $\tau \approx \tau_c \cdot (R/\lambda_D)^2$, *Crooks(1994)*



Confinement time 2.)

- With magnetic surfaces – figure-8

Variation of magnetic field & electric potential on magnetic surface + momentum conservation =>

Confinement time $\tau \approx \tau_c \cdot (a/\lambda_D)^4$, *Pedersen(2003)*

Example:

Figure-8, B ~ 5T, 150 keV protons, $n_B = 6.6 \cdot 10^{16}\ m^{-3}$

j_B=5.7 A/cm^2 → a = 1cm, I=18A, $a/\lambda_D \sim 1$, kT ~ 119 keV

$a/\lambda_D \sim 100$, kT ~ 12 eV

Instabilities

- changing of magnetic surface (big current)

Magnetic reconnection, magnetic islands, sawteeth instability

- Electrostatic instability – diocotron

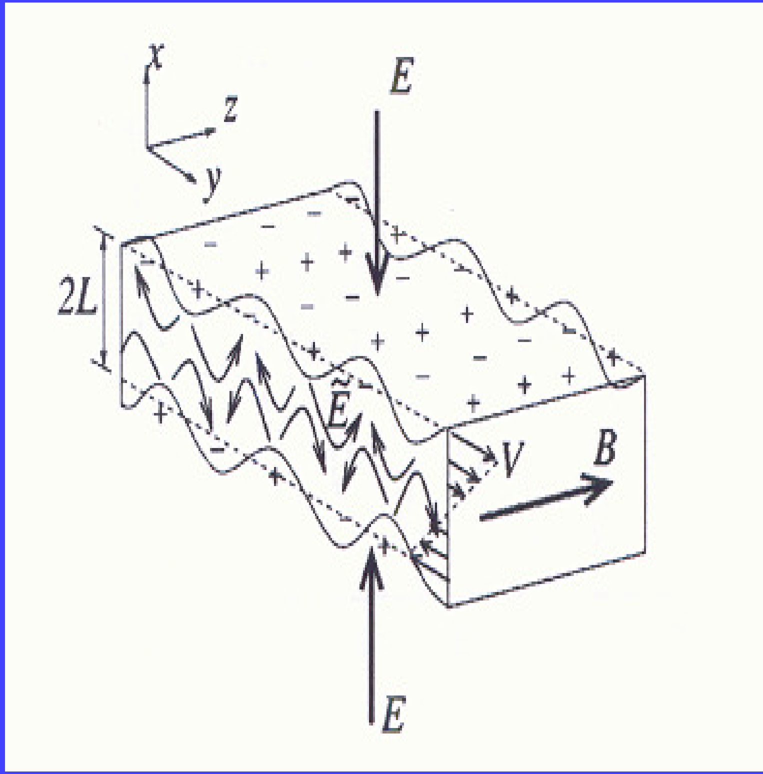
ExB drifts

- Other drifts -

Diocotron instability

- Shear in ExB drift
- Surface waves
- stable
- unstable

Instability could also work in interaction with protons in strong B-fields ($\Omega_c = \omega_D$)



Diocotron in cylindrical symmetry

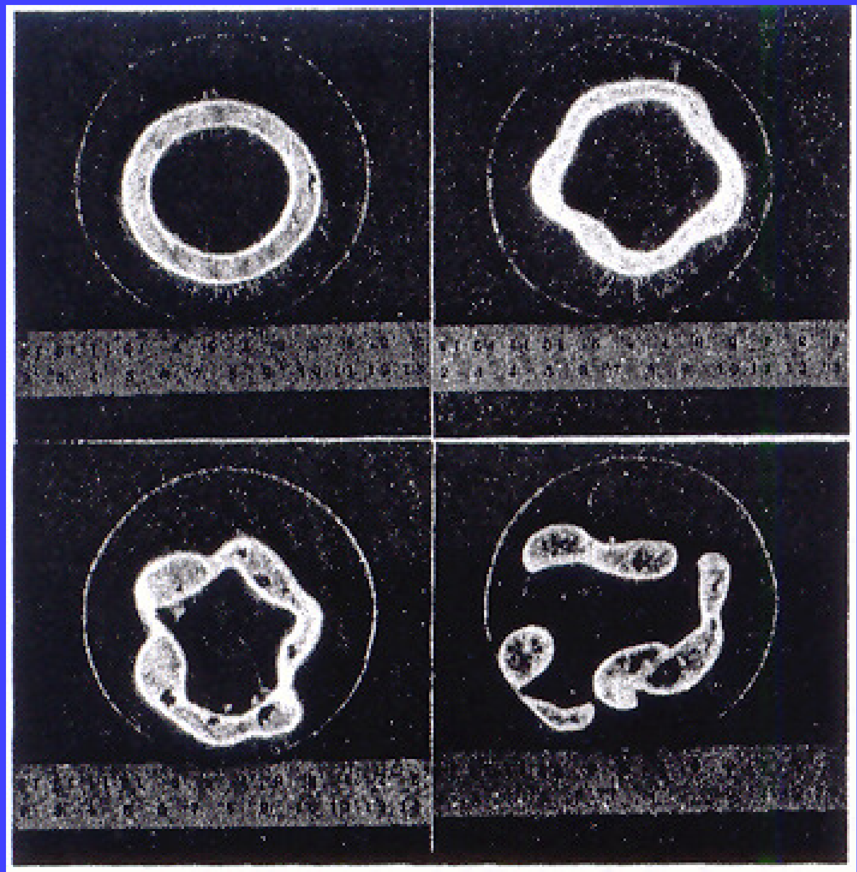
- Dependence on transversal density profile – hollow beam
- (l=1 mode) $\omega = Q/(2\pi\varepsilon_0 \cdot B \cdot r^2)$
- *Example: Gabor lens*

r ~ 0.05 m

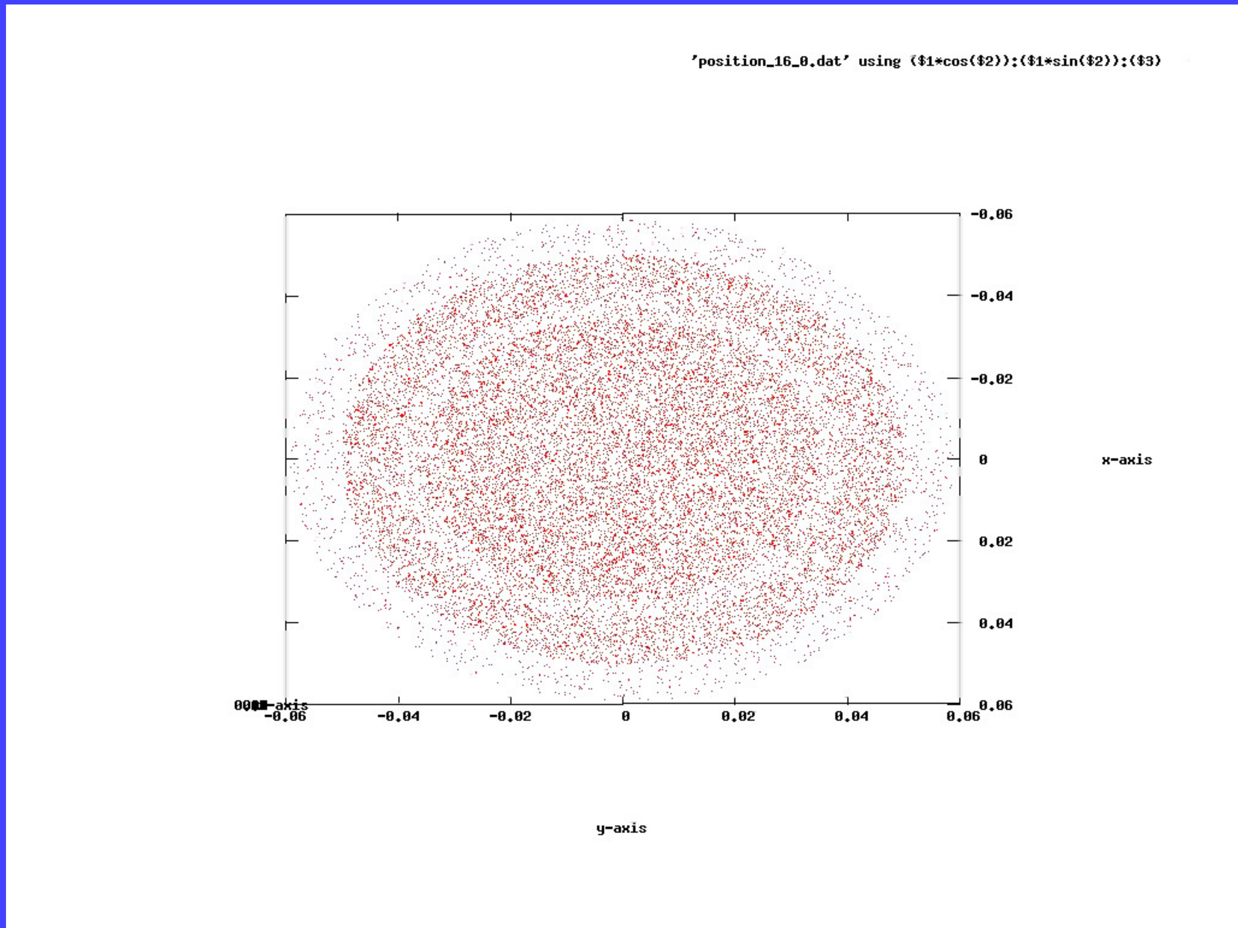
B ~ 6.6 mT

n ~ 10^{14} m^{-3}

τ ~ 10^{-7} s



Simulations – Gabor lens



Planned Work

- Equilibria of Figure-8
- Dynamic simulations of confined NNP in Figure-8 with space charge
- Possible diocotron instabillities and damping
- Changing of magnetic surfaces (rotational transformation) due to current